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(54) **GSM time and frequency synchronization using complex correlation of samples of a burst signal**

(57) A method of and apparatus for detecting a frequency burst signal in a digital phone apparatus in which, as shown in Figure 2, received signals are sampled and a window complex correlation value is repeatedly calculated in accordance with the formula

$$Z = \left| \sum_{K=\phi}^{K=K_{max}} S_K \cdot S^*_{K-L} \right|^2$$

where S_k is the complex value of the Kth sample in the window; S^*_{KL} is the complex conjugate of the (K-L)th sample and K_{MAX} is the number of samples required to include a complete frequency burst, L is an integer greater than one. A frequency burst signal is recognised when the window complex correlation value exceeds a threshold. The window is progressively moved between calculations.

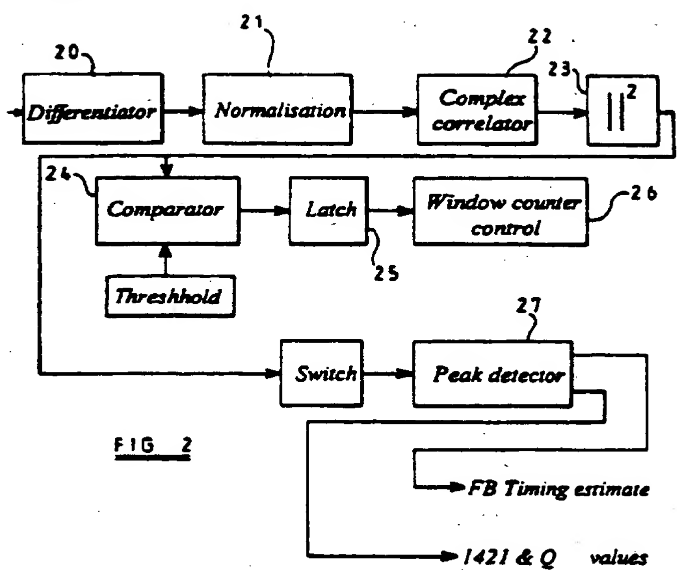

FIG 2

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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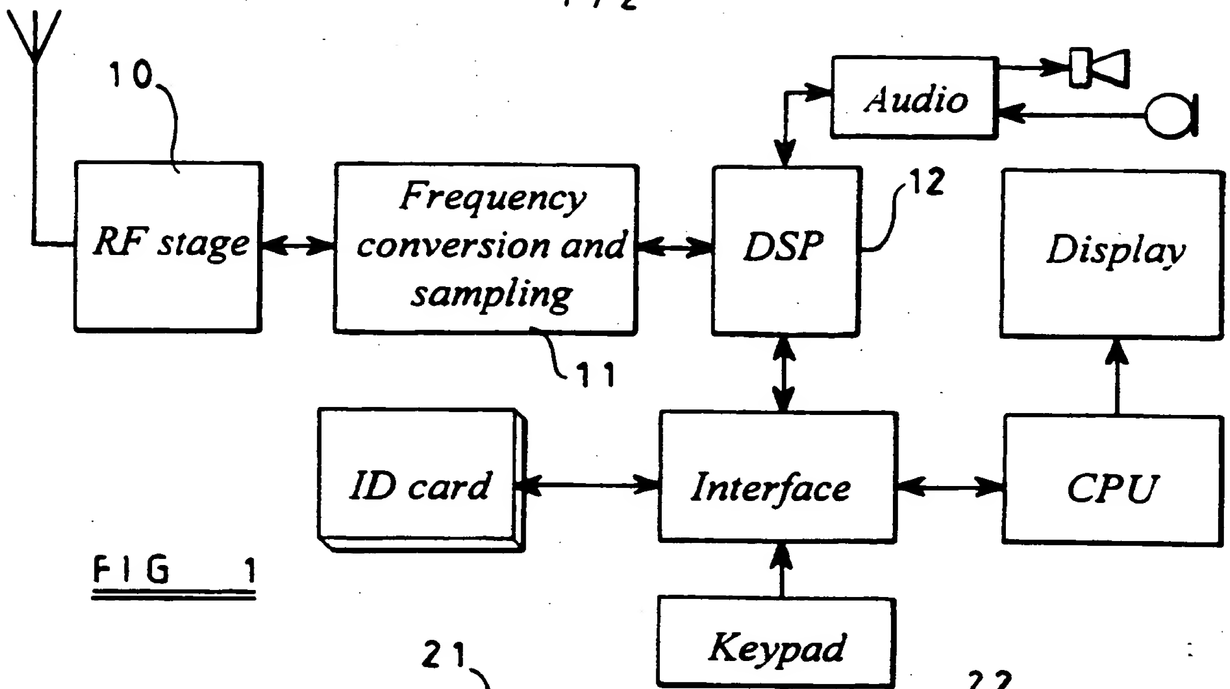
10
RF stage
Frequency conversion and sampling
11
DSP
12
Audio
Display
ID card
Interface
CPU
Keypad

FIG 1

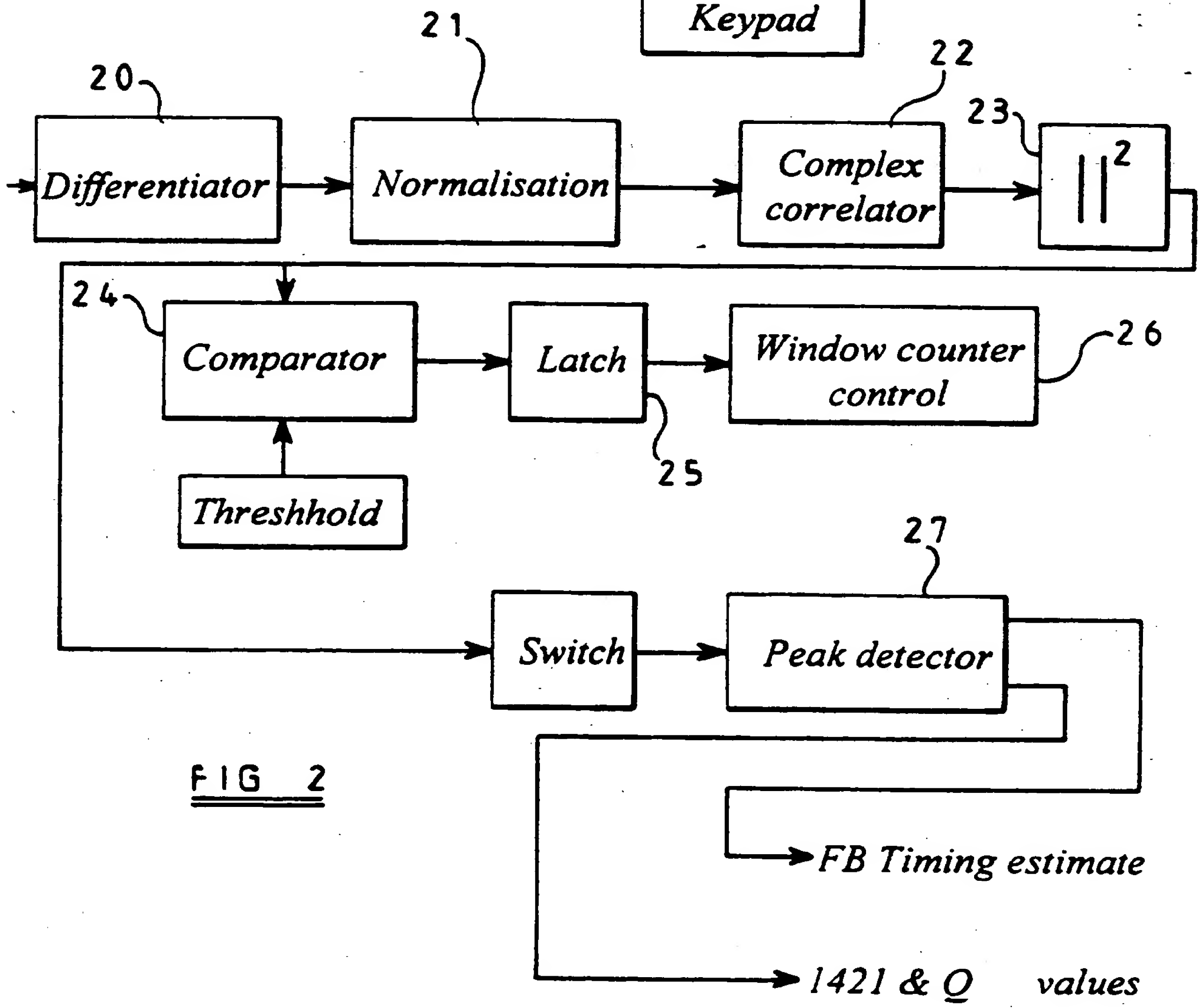
20
Differentiator
21
Normalisation
22
Complex correlator
23
| |2
24
Comparator
Latch
Window counter control
26
25
Threshhold
27
Switch
Peak detector
FB Timing estimate
1421 & Q values

FIG 2

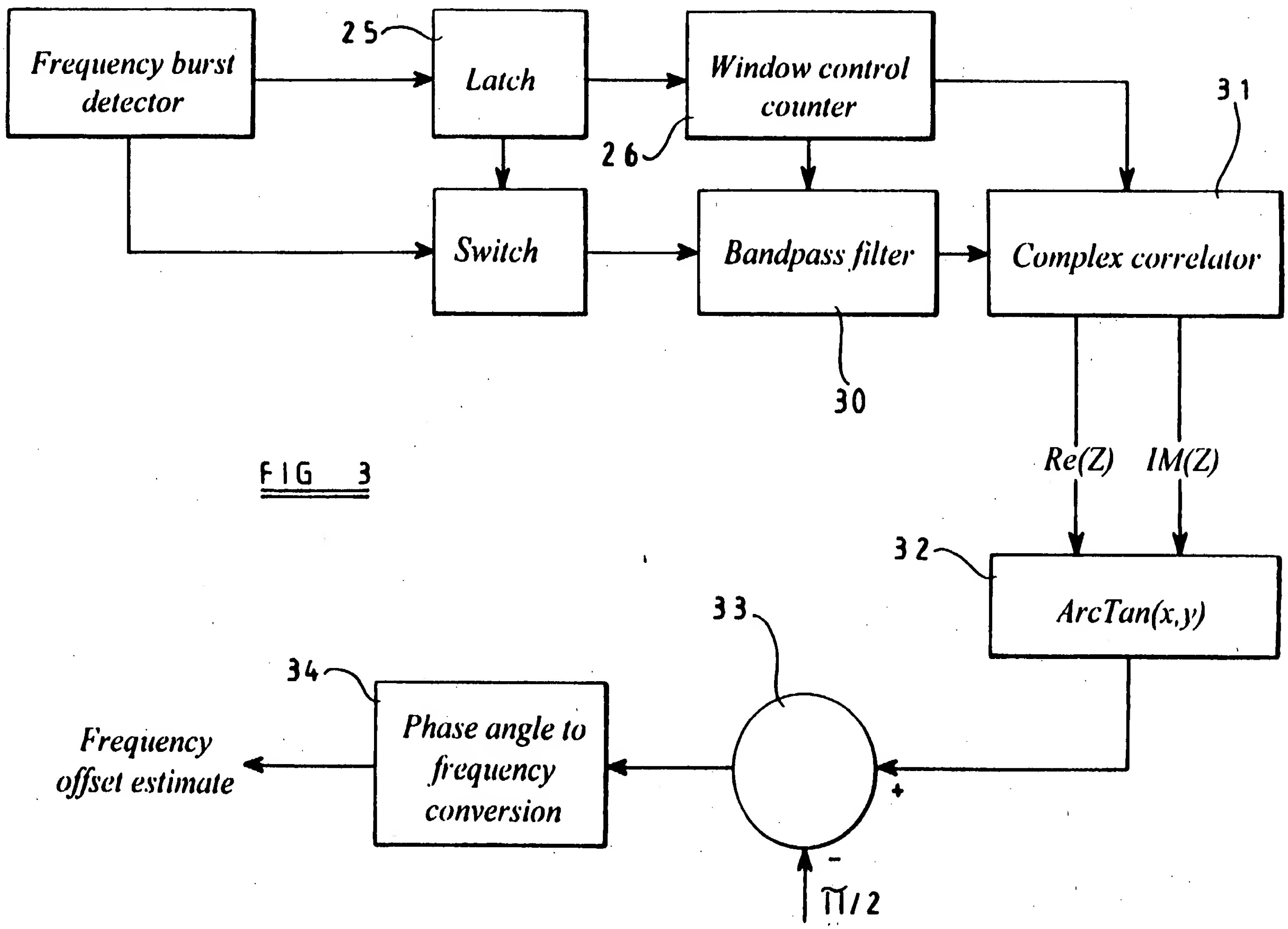
Frequency burst detector
Latch
Switch
Window control counter
Bandpass filter
Complex correlator
Re(Z)
IM(Z)
ArcTan(x,y)
+
-
π/2
Phase angle to frequency conversion
Frequency offset estimate
25
26
30
31
32
33
34

FIG 3

GSM COARSE TIME AND FREQUENCY SYNCHRONISATION

This invention relates to a process apparatus for achieving coarse time synchronisation in the GSM mobile telephone system.

Accurate reception and transmission of data in a GSM telephone system are dependent on proper synchronisation of mobile stations with base stations. To enable such synchronisation to be achieved, GSM base stations broadcast frequency bursts on a broadcast common channel (BCCH). A frequency burst consists of 3 tail bits, 142 fixed bits, 3 further tail bits and 8.25 guard bits. The 142 fixed bits correspond to an unmodulated carrier 67 KHz above the nominal carrier frequency in a TDMA (time division multiple access) timeslot. A frequency burst is transmitted in TDMA timeslot 0 during frames 0, 10, 20, 30 and 40 for a 51 multi-frame so that there is always at least one frequency burst in any group of 11 TDMA frames. The carrier 67 KHz is equal to Fs/4, where Fs is the sampling frequency, Fs = 270,833 Hz.

It has already been proposed to recognise the frequency bursts by normalising the frequency burst signals, derotating the normalised frequency burst signal by $\pi/2$, detecting the normalised, derotated frequency burst signal energy over 16 bits, incrementing a detection counter by 1 if the detected energy exceeds a threshold, and determining whether the counter is incremented by 8 or more over 160 bits. This method has been found to be computationally acceptable, but has a relatively large frequency burst detection failure rate over static and dispersive channels.

In accordance with one aspect of the present invention, there is provided a method of detecting a frequency burst signal in a digital mobile phone apparatus which comprises sampling the signals in which the frequency bursts are to be detected, repeatedly calculating a window complex correlation value

$$Z = \left| \sum_{K=\phi}^{K=K_{max}} S_K \cdot S^*_{K-L} \right|^2$$

where S_K is the complex value of the kth sample in the window, normalised to unity magnitude, K_{MAX} is the number of cycles expected in a burst, S^*_{K-L} is the complex conjugate of the (K-L)th sample, L is an integer greater than one, and determining where the window correlation value exceeds a predetermined threshold value.

Preferably, the value of L is 6 to alleviate intersymbul interference due to modulation and possible multi-path propagation.

The "window" of K_{MAX} (142 in the case of GSM) samples included in the complex correlation calculation is repeatedly moved by B sample intervals, so that the B oldest samples are excluded from each new calculation and B new samples are included instead where B is an integer greater than or equal to one. With this arrangement the value of the complex correlation value for each new block of B bits can be calculated and stored. Each new detection calculation then involves substraction from the last window complex correlation value of the B-bit value calculated for the oldest B bits and addition of the B-bit value calculated for the new B bits.

This provides an algorithm for FB detection which is no more computationally complex than the previously proposed procedure and with a significantly lower FB detection error rate.

The process also permits estimation of the position of the FB signals by locating the window position where the window complex correlation value reaches a maximum value.

Preferably, where the circuitry of the phone is such that there is likely to be a dc offset in the sample values, the detecting method of the invention preferably includes a differentiation step before the normalisation step so as to form sample values related to the rate of change of the original sample values.

In its simplest form the differentiation step can merely consist of subtracting from each sample value, the previous sample value. Separate differentiation steps are carried out on both the in-phase and quadrature components of the samples.

Differentiation largely obviates the possibility of false detection which can occur when the dc offset is left uncorrected, but does not require any modification of the circuitry to remove the dc offset.

In accordance with another aspect of the present invention there is provided a method of obtaining an estimate of the frequency offset between the frequency of frequency burst signal received in a digital telecommunication frame and the expected frequency thereof which comprises detecting the occurrence of a frequency burst by analysing a plurality of samples of the received signal, applying a group of M such

samples judged to be at the centre of the burst to a complex correlation analysis by calculating the complex value

$$Z = \sum_{K=1}^{M} x_K \cdot x^{*}_{K-1}$$

where X_K is the complex value of a sample which results from band pass filtering of the sample stream, and X^*_{K-1} is the complex conjugate of the complex value of the immediately preceding sample calculating from the value Z an accumulated phase error estimate between the signals expected and the signals actually received and converting the calculated accumulated phase error into a frequency offset estimate.

Preferably the accumulated phase error estimate is calculated by deriving the value of the arc tangent of the phase angle of the complex value Z and subtracting $\pi/2$ from it.

The invention also provides a digital telephone apparatus which includes a frequency burst detector for detecting the occurrence of a frequency burst in a broadcast common channel, said frequency burst detector including sampling means for periodically sampling the signals on the broadcast common channel and storing complex values representing the samples, normalising means for normalising such samples to unity magnitude, a window complex correlation value generator which repeatedly computes the value of the expression

$$\left| \sum_{K=\phi}^{K=K_{max}} S_K \cdot S^{*}_{K-L} \right|^2$$

where S_K is the normalised complex value of the Kth sample in a correlation window, K_{MAX} is the number of samples required to contain a complete frequency burst, S^*_{K-L} is the complex conjugate of the (K-L)th normalised sample and L is an integer greater than one, and comparison means for determining when the value of such expression exceeds a predetermined threshold.

In the accompanying drawings:

Figure 1 is a block diagram of a GSM mobile telephone apparatus,

Figure 2 is a functional block diagram of an example of a frequency burst detection system in accordance with the invention, and

Figure 3 is a functional block diagram showing the estimation of a frequency value.

Referring firstly to Figure 1, the telephone includes an RF stage 10 which is followed by an analog frequency conversion stage 11 which, among other functions, takes samples of the in-phase and quadrature components of the received signal at regular intervals and passes these in blocks to a digital signal processor 12 which converts the same to digital format and stores them in a circular buffer. The buffer can hold 320 such I and Q pair samples and the buffer is refreshed periodically and new values are written in. The circuit 10 typically passes the sample pairs to the DSP in blocks of 16 pairs, so that the buffer holds, at any given time, the 20 most recent blocks of I, Q pair samples.

The circuitry of the telephone can operate in several different modes, but the present description is concerned only with the operation of circuitry for detecting frequency bursts on the broadcast common channel of a base station, estimating the timing of the bursts for subsequent fine synchronisation (not covered by this description) and estimating the value of any frequency offset which may be found to exist (as a result of Döppler shifts or other effects).

Figure 2 is a functional block diagram showing the functions carried out, in the software of the DSP. Firstly, there is a software differentiator 20. This operates by subtracting from each I or Q sample value held in the buffer the value of the preceding I or Q sample value to derive a value representing the difference between the sample values. If there is any dc offset added to the sample values by the circuitry of circuit 11 or by the analog to digital conversion circuits of the DSP 12 this subtraction operation will remove the offset. Since the waveform being sought by the detector is effectively a sine-wave at a frequency which is one quarter of the sampling frequency it will be understood that differentiation has no undesirable effects on detection.

The differentiator is followed by a normalisation means 21 realised in the DSP software. This normalises the value of each sample by carrying out the calculation:

$$S_K = \frac{r_K}{\sqrt{\left(\sum_{0}^{N} r_i^2 / N\right)}}$$

where S_K is the normalised value of the kth sample, r_K is the absolute value of the kth sample and N is the number of samples to be taken into

account. Conveniently N is 32 which is large enough to alleviate the effect of additive noise, but short enough to account for signal fading.

The normalisation means calculates a new value for $\sqrt{\sum_{0}^{n-1} r_j^2 / N}$ every 32 sample cycles and uses that value for normalising the sample values for the next 32 sample cycles. The normalised values are stored in the circular buffer, the original sample values being overwritten.

The complex correlator 22 repeatedly calculates a value given by the expression

$$\sum_{K=0}^{K=141} S_K \cdot S^*_{K-L}$$

where S_K is the complex value $(I_K + jQ_k)$ of the kth normalised sample I, Q pair and S^*_{K-L} is the complex conjugate of the value $(I_{K-L} + jQ_{K-L})$ of the (K-L)th sample where L is an integer which is greater than 2. A value of $L = 6$ has been found to give the satisfactory results.

To avoid repeatedly calculating 142 products and adding these together the complex correlator 22 in fact uses the previously stored value of the expression, subtracts from this the product in respect of the earliest sample and adds to it the product in respect of a new sample in each cycle of operation. The product values are stored so that each has to be calculated only once.

Alternatively, the samples may be dealt with in blocks of B samples where B is an integer greater than one. In this case, for each new block of B samples, the sum of the product values is formed and stored. This

is added to the previous value of the correlation expression and the stored value for the oldest block is subtracted. It will be understood that setting the value of B to more than one will result in a significant reduction in the computational complexity and data storage requirement for the complex correlator, but will reduce the accuracy with which the timing of the frequency bursts can be estimated.

A further processing block 23 forms the square of the magnitude of each correlation value calculated by the correlator 22 and forwards this value to a comparator 24 which compares it with a threshold value. This provides a reliable indication of whether the 142 samples used in the correlation value, include a significant number of samples which represent part of a frequency burst signal. Noise and interference at frequencies other than the frequency burst signal frequency are substantially rejected. The value produced by the correlation calculation will be close to zero when there is only noise present and increase to a maximum when all 142 samples are within the frequency burst.

Figure 2 also includes a latch 25 which is set by the comparator when the correlation value exceeds the threshold value. This latch 25 starts a counter 26 which counts cycles of detector and a peak detector 27 which compares each correlation value with the previous one. When a peak value is detected, the 142 samples included in the correlation calculation can be assumed to be entirely within the frequency burst and the count held by counter 26 therefore represents the timing of the end of a frequency burst.

Figure 3 shows, in block diagram form, a frequency offset estimator which forms a part of the system described. This operates by processing

a central M sample from the 142 differentiated and filtered I and Q samples used in the calculation of the peak detection value. M is an integer which is small enough to allow for a 20-bit error in the FB location estimate, but the larger M is the more accurately can the frequency offset be estimated. A value of 82 has been found to be close to optimum and is also compatible with other GSM functions.

The frequency offset estimator includes a digital band pass filter 30 which has an IIR Tchebbychev type II band pass characteristic with its centre frequency at one quarter of the sample frequency and a bandwidth of 20kHz at -3dB. Such a filter can operate on a sine waveform with an offset of $\pm$10kHz with little or no attenuation due to filtering. The band pass filter reduces the level of fluctuations which would occur in the offset estimation in its absence.

Under the control of the counter 27 the filter 30 passes filtered I and Q sample pairs to a complex correlator 31 which calculates the value of

$$Z = \sum_{1}^{82} X_n \cdot X_{n-1}^{*}$$

where X_n is the complex value $I_n + jQ_n$. The real and imaginary parts of the value Z are passed to an arctangent calculation is carried out in block 32. Since successive samples are assumed to rotate by $\pi/2$ radians in each bit period (the FB frequency is a quarter of the sample frequency). The arctangent calculation will derive a value $\pi/2 + \Delta\phi$ where $\Delta\phi$ is an accumulated phase error over the 82 sample period. A summer 33 removes the $\pi/2$ component and a radian.to.hertz converter 34 calculates the frequency offset from the accumulated phase error.

It will be understood, by those skilled in the art, that the system described above enables accurate detection of the presence of the frequency burst, a good estimation of the timing of the frequency burst and of the error between the expected frequency and the actual received frequency (caused, for example, by Döppler shifts, multi-path propogation and/or temperature related frequency drifting) without requiring time-consuming complex calculations or heavy data storage.

Although the frequency offset estimator described above is used in conjunction with the frequency burst detector and coarse time estimator of Figure 2, it is to be understood that it could be used with any other form of frequency burst detection. As the detector of Figure 1 uses differentiated, normalised sample values which are written into the circular sample buffer over the raw sample values, these processed values are also used by the frequency offset estimator. However, if the frequency offset estimator is used in a situation where the raw sample values are retained in memory these may be used in the offset estimator to equal effect.

CLAIMS

1. A method of detecting a frequency burst signal in a digital phone apparatus which comprises sampling the signals in which the frequency bursts are to be detected, repeatedly calculating a window complex correlation value

$$Z = \left| \sum_{K=0}^{K=K_{max}} S_K \cdot S^*_{K-L} \right|^2$$

where S_K is the complex value of the Kth sample in the window; S^*_{K-L} is the complex conjugate of the (K-L)th sample and K_{MAX} is the number of samples required to include a complete frequency burst, L is an integer greater than one, and determining when the window correlation value exceeds a predetermined threshold value.

2. A method as claimed in Claim 1, in which there are four samples in each cycle of the expected frequency burst and the value of L is 6.

3. A method as claimed in Claim 1 or Claim 2, in which the window of K_{MAX} samples included in the complex correlation calculation is repeatedly moved, so that the B oldest samples are excluded from each new calculation and B new samples are included instead, where B is an integer greater than or equal to one.

4. A method as claimed in Claim 3, in which the value of B is 1 and in which for each new window correlation value calculation, the value of $S_K \cdot S^*_{K-L}$ is calculated in respect of the new sample to be

included added to the previously calculated window correlation value and stored, and the stored value of $S_0 \cdot S_K{}^*{}_{-1}$ being based on the oldest sample in said previously calculated window correlation value is subtracted.

5. A method as claimed in any preceding claim, including the further step of estimating the timing of the FB signals, by ascertaining when the calculated window correlation value reaches a peak value.

6. A method as claimed in Claim 5, which comprises counting the number of window calculations made between detection of the window correlation value exceeding its threshold value and the window correlation value achieving its peak value.

7. A method as claimed in Claim 5 or Claim 6, including the further step of estimating the frequency offset between the expected frequency burst signals and the frequency burst signals actually detected by calculating a centre complex correlation value for a number M of the samples estimated to be at the centre of the frequency burst the centre complex correlation value being in accordance with the expression

$$Z = \sum_{1}^{M} X_K \cdot X^*_{K-1}$$

where X_K is the complex value of a sample which results from band pass filtering of the sample stream; calculating an accumulated phase error estimate between the signals expected and the signals actually received and converting the calculated accumulated phase error into a frequency offset estimate.

8. A method as claimed in Claim 7, in which the accumulated phase error estimate is calculated by deriving the value of the arc tangent of the phase angle of said centre complex correlation value Z and subtracting $\pi/2$ therefrom.

9. A method as claimed in any preceding claim, in which the samples are processed before normalisation by differentiation to eliminate any dc offset component thereof.

10. A method as claimed in Claim 9, in which differentiation is effected by subtracting from the I and Q components of each sample, the I and Q components of the immediately preceding sample.

11. A method of detecting a fixed frequency signal burst in a digital phone apparatus comprises:

(a) storing in memory the values of a plurality of the real and imaginary components of sequential samples of a received signal in which the fixed frequency burst is expected,

(b) processing each sample by subtracting from the real and imaginary components thereof the real and imaginary components of the immediately previous sample,

(c) normalising the sample so processed by scaling the real and imaginary components thereof to make its absolute value approach unity,

(d) calculating the product of each normalised processed sample value and the complex conjugate of a normalised processed sample value one or more samples earlier in the sample sequence,

(e) adding the product to a previously calculated complex correlation value

$$\sum_{K=M}^{K=M+K_{max}} S_K \cdot S^*_{K-L}$$

where $S_K \cdot S^*_{K-L}$ is the value of said product for the kth sample,

(f) subtracting from the result, the earliest product in the correlation value $S_M \cdot S^*_{M-L}$, so as to form a new window complex correlation value,

(g) comparing the magnitude of the complex correlation value with a threshold value and repeating steps (b) to (g) until the magnitude of the new window complex correlation value is found to exceed the threshold value.

12. The method as claimed in Claim 11, comprising the further steps of continuing to repeat steps (b) to (f) after the magnitude of the window complex correlation value has exceeded the threshold value and comparing the magnitude of each new window complex correlation value with the magnitude of the immediately previous window complex correlation value until it is found that the new window complex correlation value is less than the immediately previous complex correlation value and producing an estimate of the timing of the frequency burst in the time frame of the phone from the timing of this comparison event.

13. A method of estimating the frequency offset between the frequency of a frequency burst signal in a received digital telecommunication signal frame and an expected frequency thereof comprising:

(a) detecting the occurrence of a frequency burst by analysing a plurality of samples of the received signal;

(b) applying a group of M such samples judged to be at the centre of the burst to a complex correlation analysis, by calculating the complex value

$$Z = \sum_{1}^{M} X_K \cdot X_{K-1}^{*}$$

where X_K is the complex value of a sample which results from band pass filtering of the sample stream; and X^*_{K-1} is the complex conjugate of the complex value of the immediately preceding sample;

(c) calculating from the complex value Z an accumulated phase error estimate between the M signals expected and the M signals actually received; and

(d) converting the accumulated phase error estimate into an estimated frequency offset.

14. A method as claimed in Claim 13, in which said accumulated phase error estimate is calculated by deriving the value of the arc tangent of the real and imaginary components of the complex value Z.

15. A digital telephone apparatus comprising a frequency burst detector for detecting the occurrence of a frequency burst in a broadcast common channel, said frequency burst detector including sampling means for periodically sampling the signals on the broadcast common channel and storing complex values representing the samples, normalising means for normalising such samples to unity magnitude, a window complex correlation value generator which repeatedly computes the value of the expression

$$\left|\sum_{K=\phi}^{K=K_{max}} S_K \cdot S^*_{K-L}\right|^2$$

where S_K is the normalised complex value of the Kth sample in a correlation window, K_{MAX} is the number of samples required to contain a complete frequency burst, S^*_{K-L} is the complex conjugate of the (K-L)th normalised sample and L is an integer greater than one, and comparison means for determining when the value of such expression exceeds a predetermined threshold.

16. An apparatus as claimed in Claim 15, in which the value of L = 6 and in which the sample frequency is four times the expected burst frequency.

17. An apparatus as claimed in Claim 15 or Claim 16, comprising means for storing a plurality of values of

$$Z = \sum_{i}^{B} X_K \cdot X^*_{K-L}$$

where B is an integer greater than or equal to one and less than K_{MAX} for use in successive correlation calculations.

18. An apparatus as claimed in Claim 17, in which the value of B is 1, and the complex correlation value generator operates to calculate the value of $X_K \cdot X^*_{K-L}$ for each new sample, add such value to the existing complex correlation value and subtract the oldest value of $X_K \cdot X^*_{K-L}$ from sum.

19. An apparatus as claimed in any of Claims 15 to 18, further comprising a maximum value detector for detecting when the complex correlation value calculated reaches a peak and estimating therefrom the timing of the frequency burst.

20. An apparatus as claimed in any of Claims 15 to 19, further comprising offset estimating means for estimating the frequency offset between the expected frequency burst signals and the frequency burst signals actually received, such offset estimating means comprising band pass filter means through which a group of M of the samples judged to be in the centre of the frequency burst are passed, and a centre complex correlation value calculation means for calculating the value

$$Z = \sum_{K=1}^{M} X_K \cdot X_{K-1}^{*}$$

phase error estimation means for calculating an estimated phase error between the expected frequency burst signal and that actually received accumulated over the M cycles included in the calculation of Z from the value of Z.

The Patent Office

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Application No:	GB 9614354.0	**Examiner:**	David Midgley
Claims searched:	1-20	**Date of search:**	25 October 1996

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): H4P (PDRX,PAL,PAQ,PDX)

Int Cl (Ed.6): H04B 7/212; H04J 3/06; H04L 27/156,27/227,27/233,27/38

Other: ONLINE:WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	GB 2251161 A (Motorola) whole doc.	1,11,13,15

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.